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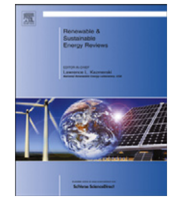

Characterization and mapping of waste from coffee and eucalyptus production in Brazil for thermochemical conversion of energy via gasification

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The generation of waste is an intrinsic characteristic of forestry and agricultural production and has become a major concern. Brazil is a great agricultural producer, and in recent years both the planted area and crop production have grown significantly, with a corresponding increase in agricultural waste. In the context of climate change, efficiency and energy security, it is fundamental to develop alternative energies that meet the needs of both the energy supply and sustainable development. Wood chips and coffee husks are low cost residues and potentially capable of generating heat, steam and electric power, thus they can serve as an alternative fuel for generating energy. This work aims to relate the agricultural market to the energy market, using waste from coffee and eucalyptus production to generate energy, as well as mapping waste production in Brazil by region. It was observed that Brazil has a great capacity to generate alternative energy, since approximately 11.4×10^6 t of wastes are generated per year from coffee and eucalyptus production alone. These wastes can be used for the thermochemical conversion of energy via gasification, with potential to generate a total of 201.3 PJ.

Contents

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1. Introduction

The large volume of waste generated by the wood processing and agricultural industries is a problem that exists in almost all regions of Brazil. Multiple environmental problems result from the contamination of soil and groundwater due to the accumulation and improper disposal of residues from forestry and agriculture industries.

Thus, the term residue is often considered problematic, because its disposal or proper use usually generates high costs that producers often want to avoid. However, knowledge of the quantity, quality and possible uses of this material can produce an alternative that conserves energy and contributes to sustainable development.

Brazil has a great potential for creating energy from biomass as a substitute for petroleum. Taking into account the large size of Brazil's forests, coupled with the possibility of using timber and agricultural residues, Brazil has the ideal conditions for this change. Waste from forestry and agricultural production forms biomass that can be exploited. Wood chips and coffee husks provide low cost residues that are renewable and underused, environmentally friendly and potentially capable of generating heat, steam and electric power. Thus they may constitute an alternative fuel for producing energy.

Large amounts of waste are available from the timber industry, production of charcoal and the processing of agricultural products like coffee and rice. Of the total waste generated by agricultural and forestry activities, approximately 65% comes from the timber industry (excluding the direct use of wood for heating). In this industry, the production of wood shavings may reach 16% of the total volume of the original wood. In coffee production, approximately 21% is converted into solid waste, husk, and parchment, with a calorific value of 17,500 kJ kg^{-1} [1]. Coffee husk is not often used as an energy source in thermochemical processes. This waste is frequently applied to soil as fertilizer, because it is rich in potassium. However, potassium is present in the ash produced after conversion process, which also allows its use in agricultural crops [2].

The coffee production chain produces another unexplored waste, wood coffee. An adult coffee plant weighs on average 15 kg (dry wood), however approximately 25% of coffee becomes waste in the form of wood after pruning, which occurs approximately every five years. Therefore, the coffee production chain includes alternative energy sources, which could be used for providing some of the energy required by the chain itself.

The use of biomass as energy source offer many economical, social and environmental benefits such as financial net saving, conservation of fossil fuels, income generation, and reduction of CO_2 and NO_x emission. However, environment impacts can exist, and need special attention to land and water resources, soil erosion, loss of biodiversity and deforestation [3].

The least sustainable biomass generation example occurs when energy crops compete with food crops or when energy crops are grown using high amount of fertilizers. Integrated solution are sustainable as the fuels is a waste product directly generated and reused on-site, reducing land and water use, or when the process generates materials or chemicals besides energy [4,5].

Biomass-based energy has several advantages such as wide availability and uniform distribution. Especially, in the remote areas, biomass gasification-based power generation offers a highly viable solution for meeting energy demands of small villages and hamlets, which would not only make them independent but would also reduce burden on state electricity boards [6].

Accordingly previous argument, this work presents an overview about waste from coffee and eucalyptus production in Brazil and thermochemical potential for utilization on brazilian electrical energy source.

1.1. Biomass for energy worldwide

Sustainable biomass production from plantation is estimated to be in the range of 182.5–210.5, 62–310, 0.4–1.7, 3.7–20.4, 2.0–9.9 and 11.6–106.6 Mt yr^{-1} for China, India, Malaysia, Philippines, Sri Lanka and Thailand, respectively. The maximum annual electricity generation potential, using advanced technologies, from the sustainable biomass production is estimated to be about 27%, 114%, 4.5%, 79%, 254% and 195% of the total electricity generation in year 2000 in China, India, Malaysia, Philippines, Sri Lanka and Thailand, respectively. Investment cost for bioenergy production varies from US$381 to 1842 ha^{-1} and investment cost for production of biomass varies from US$5.1 to 23 t^{-1}, in the countries considered [7].

An assessment of biomass resources in Shangai, in 2005, estimates approximately 8 million tons of biomass that can be converted in energy: agricultural residues, forest and wood mill residues, municipal solid wastes and excrement resources. This biomass generates an annual energy potential of 1.7149 million - tons of coal equivalent (TCE) [8].

Biomass samples and socio-economic data have been collected at district level in the rural areas of Indo-Angetic Plain (IGP), India to determine the emissions of trace gases and aerosols from domestic fuels. Dung cake, fuel wood and crop residue are main sources of energy in rural areas of the IGP. Dung cake is the major domestic fuel (80%–90%) in the rural areas of Delhi, Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal, whereas, 99% of rural households in Uttarakhand use wood as the main energy source. Using crop production data and usage of crop residues as energy, new consumption values have been estimated (21.13 Mt) [9].

The main constraints to develop biomass technology in Malaysia are the lack of information for using biomass as an alternative to generate electricity, as well as risk probabilities associated with applying new technology, high cost compared with conventional energy generation, market demand and government policy [10].

Traditional fuels like firewood, dung and crop residues currently contribute a major share in meeting the everyday energy requirements of rural and low-income urban households in Pakistan. An average biomass using household consumes 2325 kg of firewood or 1480 kg of dung or 1160 kg of crop residues per annum [11].

Slovakia and the Czech Republic have large amounts of biomass that is potentially available for energy purposes hidden in unused crop and wood residues and in residual biomass in permanent grasslands. In sum, 3544 kt yr^{-1} of unused biomass in Slovakia could replace 53 PJ yr^{-1} of heat from fossil fuels and 6293 kt yr^{-1} of unused biomass could replace 91 PJ yr^{-1} of heat from fossil fuels in the Czech Republic. Such replacement could contribute to a total decrease in CO2 emissions of 9.2% in Slovakia and of 5.4% in the Czech Republic and could thus contribute to an environmental improvement with regard to climate change [12].

In Switzerland, there is a substantial potential from wood biomass, manure and waste biomass. However, economic factors, swiss biofuels policy and competing material utilizations are restrictions that limit the sustainable biomass potential. In last years, 3.6% of Switzerland's energy demand was met by biomass resources, whereas the remaining potential could provide an additional 3.3% [13].

A target of 30% substitution of biomass for peat in the three peat fired power stations from 2015 has been set by the Irish Government. However, a knowledge gap exists on the extent to which Irish farmers would actually choose to grow these crops. An extension of the renewable energy feed in tariff (REFIT) scheme to include the co-firing of biomass with peat in electricity

generation would enable the power stations to enter into power purchase agreements (PPAs). These offer a fixed price to farmers for biomass feedstock, which created an impasse to reach the target [14].

Boukis et al. [15] studied the current situation and prospects of biomass availability and exploitation in Greece and developed a methodology to introduce the conversion of biomass into energy products.

In Spain, policy instruments have been used since 1980 to stimulate biomass power generation. However, the diffusion outcome by 2007 was only 525 MW. Two factors lie at the core of this: the conceptualization of biomass resources by political decision-makers in the instruments used, and the desire that policy instruments be in line with market liberalization principles [16]. In 2012, García et al. [17] studied more than 200 different potential biomass fuel originating in every point of Spain. Nitrogen and sulfur content were low in most samples which lead to low emissions of NO_x and SO_2. However, the ash content and high heating value appears in acceptable values.

Pruning olive trees in Mediterranean areas produce residual biomass that can be used as a source of energy or as raw material for the wood industry. It provides additional income and more sustainable system for fruit producers. The residual biomass from olive pruning reaches an average 1.31 t ha^{-1} in annual pruning and 3.02 t ha^{-1} in biennial pruning [18].

1.2. Gasification as energy conversion system

Literatures support that conversion of biomass through thermochemical conversion path helps to protect environment and ecology as well [19]. In this context, technologies have been developed to improve efficiency of converting biomass into gas fuel through biomass gasification in downdraft gasifier systems. It is the most appropriate system for industrial applications such as heating and drying of agricultural products [19].

In the Brazilian Amazon, along the Madeira River, the electric needs of the communities and small towns can be satisfied through the gasification system, using as a renewable feedstock the wood-fuel biomass deposited on the riverbed, derived from natural processes, which the Ministry of Transport is already legally obligated to remove in order to provide safe navigation along the river. Comparing to a conventional diesel thermoelectric plants, the total generation cost (US$ MWh^{-1}) is 351.94 in a Diesel fired power plant, and 138.93 in a gasification system [20].

Thus, due to the large volume of biomass waste generated by the wood processing industries and agriculture, concerns have arisen regarding the use of waste for energy through the use of existing technologies. Among conversion technologies, gasification is one of the most promising for generating heat, hydrogen, ethanol and electricity. Among the benefits of biomass gasification are sustainability, reducing greenhouse gas emissions, regional economic development, social and agricultural development and a regular supply of energy.

However, the gasification process is still limited to solid fuel, since biomass involves an abundance of different materials, both in composition and properties. Green wood can contain up to 50% moisture, and therefore requires much energy for drying since combustion does not always supply enough heat to vaporize. Besides the moisture content, it is also necessary to determine the chemical composition of the biomass in order to find the amount of air required to most efficiently gasify the biomass.

Gasification behavior and process characteristics differ from each biomass chosen as energy source. The physical properties and chemical characteristics of biomasses are the main reason for differences in gas heating value [21].

This study aims to quantify and characterize waste from coffee production (husk and wood) and waste from eucalyptus production (in the form of chips) for energy purposes, conducting a survey of the bioenergy potential of these wastes in Brazil.

2. Procedure and tools

The specific mass and chemical biomass characterization were analyzed at the Alternative Energy Laboratory, Department of Agricultural Engineering and the Laboratory of Wood Energy, Department of Forest Engineering, respectively, at the Federal University of Viçosa, in Viçosa, Minas Gerais State, Brazil.

This work used waste from timber production in the form of eucalyptus chips (square-shaped with 2.2 cm sides and a thickness of approximately 0.3 cm) from the Forestry Department, waste from agricultural production of coffee in the form of husks (hollow semi-ellipsoid-shaped with a diameter of approximately 0.7 cm) and wood (cylinder-shaped with a diameter of 2.3 cm and an approximate height of 3.5 cm) from the Department of Agricultural Engineering.

2.1. Preliminary analysis

The preliminary biomass analysis was performed according to the Brazilian Technical Standards Association (ABNT) [22], by NBR 8112/83: moisture content (MC), ash (AS), volatile matter (VM) and fixed carbon (FC).

2.1.1. Moisture content

Wet basis moisture content is the amount of water per unit mass of wet sample. The following procedure was used to determine moisture content:

Small amounts of waste (500 g) were collected to represent the whole pile. Samples were immediately placed in a closed container to preserve moisture. Three 50 g samples were separated and weighed. The samples were put in a lab incubator at 103 ± 2 °C until the difference in the weight of each sample stabilized to less than 0.2%. Moisture content was calculated using the ratio between the amount of water in the sample and its initial weight.

2.1.2. Ash content

Ash content is a measure of the amount of minerals and other inorganic materials that remain after the oxidation.

The previously dried samples, each approximately 1 g, were put in a muffle furnace at 650 ± 10 °C for 6 h. Samples were removed from the muffle furnace and cooled in a desiccator until they reached room temperature, with ash content determined by differences in weight.

2.1.3. Volatile matter

The percentage of volatile material determines the amount of gaseous products without the presence of moisture, which is released under specific conditions.

The approximately 1 g samples were dried in an incubator at 103 ± 2 °C until they reached a constant weight. The samples were placed in a muffle furnace at 950 ± 10 °C for nine minutes. Afterward, the samples were removed from the muffle furnace, placed in a desiccator until cooled, and the amount of volatile solids was determined by weight differences.

2.1.4. Fixed carbon

Fixed carbon represents the amount of carbon chemically bonded to other carbon atoms. This is obtained by the sum of the

percentages of ash and volatile material, subtracted from 100. All percentages should be on the same baseline moisture (dry or wet).

2.2. Elementary composition and calorific value

In terms of its elemental composition, and with particular reference to its C, H and O contents, biomass of different origin and type is rather similar. In general, the C content is 30%–60%, H around 5%–6%, and O around 30%–45% (wt% on dry basis).

To determine the elemental composition (carbon-C, hydrogen-H and oxygen-O) and the higher calorific value (HCV), the methodology proposed by Parikh et al. [23] and Parikh et al. [24] was used. These authors described the following algebraic equation based on preliminary analysis of the entire spectrum of solid lignocellulosic material.

$$C = 0.637FC + 0.455VM(\%) \quad (1)$$

$$H = 0.052FC + 0.062VM(\%) \quad (2)$$

$$O = 0.304FC + 0.476VM(\%) \quad (3)$$

$$HCV = 0.3536FC + 0.1559VM - 0.0078\ AS\left(MJ\ kg^{-1}\right) \quad (4)$$

Eqs. (1)–(3) are valid for solid lignocellulosic material with values of fixed carbon in the range of 4.7%–38.4%, volatile matter content between 57.2% and 90.6% and ash content between 0.12% and 77.7%, on a dry basis. Eq. (4) is valid for lignocellulosic solid with values of fixed carbon in the range from 1.0% to 91.5%, volatile matter content between 0.92% and 90.6% and ash content between 0.12% and 77.7%, on a dry basis. The mean absolute error of these correlations is 3.21%, 4.79%, 3.40% and 3.74%, for the measured values of C, H, O and HCV respectively.

2.3. Specific mass of the biomass

The specific mass of biomass represents the amount of biomass occupying the unit volume, which is determined by a balance with a one liter cylinder filled only with the biomass, in three replicates, with the results expressed in kg m^{-3}.

2.4. Energetic potential of wastes in Brazil

The research about the energy potential of biomass analyzed was performed based on a survey of agricultural and forestry production conducted by the Brazilian Institute of Geography and Statistics [25].

The amount of waste was calculated based on the percentage of unusable material after the production process. From these data, a survey about the energy potential of waste from eucalyptus and coffee production was conducted in Brazil.

According to [25], the cultivation of eucalyptus represents approximately 60% of timber production in Brazil. Excluding wood used for logs and charcoal, about 65% of wood production is characterized by waste generated by industrial activity [1]. Therefore, to estimate the energy potential (EP) of the waste from timber production, Eq. (5) was used

$$EP_{eucalyptus\ waste}(MJ) = HCV\ of\ the\ eucalyptus\ chips\ x\ eucalyptus\ waste\ mass \quad (5)$$

where

$$Eucalyptus\ waste\ mass = eucalyptus\ volume\ x\ 0.65\ x\ eucalyptus\ chips\ specific\ mass \quad (6)$$

$$Eucalyptus\ volume = volume\ of\ wood\ production\ x\ 0.60 \quad (7)$$

In coffee production, approximately 21% of the grain mass is converted into solid waste, bark and parchment [1]. Each coffee plant has an average weight of 15 kg and 25% of the total mass of the coffee trees is processed into waste wood, excluding trimming which occurs every 5 years. Therefore, to estimate the energy potential (EP) of waste from coffee production it was used the following methods:

To calculate the energy potential of coffee husk

$$EP_{Coffee\ husk}(MJ) = HCV\ of\ the\ coffee\ husk\ x\ coffee\ husk\ mass \quad (8)$$

where

$$Coffee\ husk\ mass = amount\ of\ coffee\ produced\ x\ 0.21 \quad (9)$$

To calculate the energy potential of coffee wood waste

$$EP_{Coffee\ wood}\ (MJ) = HCV\ of\ coffee\ wood\ x\ coffee\ wood\ mass \quad (10)$$

where

$$Coffee\ wood\ mass = amount\ of\ trees\ harvested\ x\ 15\ kg/tree\ x\ 0.25 \times 0.2(trimming\ every\ 5\ years) \quad (11)$$

3. Results and discussion

3.1. Biomass analysis

In preliminary analysis of the husk coffee, wood coffee, and eucalyptus chips (Table 1), we observed that the moisture content was relatively low for the biomass. This characteristic favors the use of thermochemical conversion since high moisture content harms the performance of the conversion systems. The moisture content of the biomass (less than 30%) was suitable for the gasification process, according to [26,27]. There was a small discrepancy in the other analyses of the biomass, but it was in the optimum range for the gasification process [28].

A high proportion of volatile matter allows biomass to ignite easily and together with the fixed carbon to volatile matter ratio determines the flame stability during combustion. The higher the volatile matter content, the higher the burning velocity and the lower the flame stability [29].

The values from Table 1 are in the same order of magnitude as the results obtained by [30] for wood chips: moisture 34.9%, volatiles 51.6%, fixed carbon 13.3%, and ash 0.2%.

The moisture biomass affects not only the operation of the gasifier, but also the quality of the gas produced. The water trapped in the biomass takes about 2300 kJ kg^{-1} to vaporize, and 1500 kJ kg^{-1} to raise its temperature to 700 °C during pyrolysis. However, this energy must be subtracted from the energy supplied by the combustion zone. The temperature drop in the combustion zone causes the pyrolysis zone to operate in an inappropriate manner, producing more tar than could be cracked. Although it is physically possible to gasify biomass with high moisture content, it is not economically viable.

The volatile matter is mixed with air and oxidized in the gas phase in the pyrolysis zone, while the fixed carbon remains solid and goes to the combustion zone. The products from volatile

Table 1
Biomass analysis, NBR 8112/83.

Biomass	Moisture content (%)	Volatile matter (%)	Ash (%)	Fixed carbon (%)
Coffee wood	9.61	85.73	0.94	13.33
Wood chips	9.74	90.55	0.44	9.02
Coffe husk	9.22	81.87	1.71	16.42

oxidation are then reduced to carbon monoxide and hydrogen when they pass through the combustion zone, which contains superheated fixed carbon.

In most of the biomass, the ashes are composed of salts. When the biomass has a large amount of ash (higher than 5%) it can cause serious damage to the reactors and secondary equipment (cleaning system, motors, turbines) [28].

The amount of heat generated per unit volume is also related to bulk density (Table 2).

Lower density biomass is consumed faster in the reactor. Therefore, coffee husk gasification should be conducted with replenishment as the amount of biomass in the reactor is consumed. Furthermore, coffee husk requires a large volume to generate the same amount of heat as other types of biomass. The low density of biomass causes high transport and storage costs and in many cases it is associated with high humidity that can make it impossible to use. Thus the use of waste for energy purposes should be carefully evaluated, analyzing logistical aspects of location, transport, biomass heterogeneity and storage.

El may et al. [31] investigated the characterization and thermal behavior of date palm residues. They found high bulk density (656 kg m^{-3}) for date stones which was one of the date palm wastes studied. The high value of this property makes this residue the most attractive material for energy production due to its high energetic density and then low cost transportation.

Verma et al. [32] conducted a physical and chemical characterization of wood pellets and found a bulk density of 693 kg m^{-3} for this waste residue. Wu et al. [33] studied the significant physical material properties of solid biomass fuels. The bulk density tests were conducted using two types of measuring containers: a steel pan and a1 L steel can. The measured value for wood chips was between 209 and 273 kg m^{-3}.

From the chemical analysis of the biomass, values of elemental composition and calorific values of the wastes were obtained (Table 3).

Table 2
Specific mass.

Biomass	Specific mass (kg m^{-3})
Coffee wood	416.7
Eucalyptus chips	179.8
Coffe husk	138.8

Table 3
Elemental composition and higher calorific value.

	C % (g g^{-1})	H % (g g^{-1})	O % (g g^{-1})	HCV (MJ kg^{-1})
Coffee wood	47.50	6.01	44.86	18.07
Eucalyptus chips	46.94	6.08	45.84	17.30
Coffee husk	47.71	5.93	43.96	18.56

There is a similar chemical composition of biomass studied, and higher calorific value consistent with values reported in the literature [34].

Spinelli et al. [35] determined the quantity and the quality of pruning residues potentially derived from vineyard management. The HCV of vineyard pruning residues was 18.7 MJ kg^{-1}, slightly higher than eucalyptus chips.

Sait et al. [36] studied the thermo-chemical characteristics of date palm biomass wastes like seed, leaf and leaf stem. Dates seeds showed the highest HCV of 18.97 MJ kg^{-1}among the date palm biomass. The HCV of leaf (17.9 MJ kg^{-1}) was close to wood eucalyptus chips.

Table 4
Amount of timber produced in Brazil in 2010 [6].

Region	Volume (m^3)
North	3,543,366
Northeast	15,279,979
Southeast	41,364,215
South	49,872,126
Midwest	5,663,845
Brazil (total)	115,741,531

Table 5
Amount of coffee produced in Brazil in 2010 [6].

Region	Amount (t)
North	158,037
Northeast	158,412
Southeast	2,413,241
South	139,054
Midwest	37,571
Brazil (total)	2,906,315

Table 6
Number of trees harvested in Brazil in 2006 [6].

Region	Amount (unit)
North	150,915,000
Northeast	228,276,000
Southeast	3,047,610,000
South	205,119,000
Midwest	22,696,000
Brazil (total)	3,654,616,000

Table 7
Amount of waste generated in eucalyptus and coffee production in Brazil.

Region	Eucaliptus (Gg)	Coffee husk (Gg)	Coffee wood (Gg)	Total (Gg)
North	248.5	33.2	113.2	394.8
Northeast	1071.5	33.3	171.2	1275.9
Southeast	2900.5	506.8	2285.7	5693.0
South	3497.1	29.2	153.8	3680.2
Midwest	397.2	7.9	17.0	422.1
Brazil	8116.0	610.3	2741.0	11467.3

3.2. *Energy potential of agricultural waste in Brazil*

In 2010, the Brazilian production of legalized timber increased by 8.26% over 2009, with a production of over 115 million cubic meters. Most production was concentrated in the south and southeast, as shown in Table 4.

Brazil had record coffee production in 2010 (Table 5), generating over 2 million and 900,000 tons of coffee, with the southeast being the main region of production.

According to the last farming census conducted by [25], more than 3.6 billion coffee trees were harvested in 2006. For this survey, only establishments with more than 50 coffee trees existing were considered (Table 6).

From the data of each biomass and in accordance with Eqs. (6),(9) and (11), it is possible to quantify the generation of waste in Brazil and its regions (Table 7).

As a result of being the greatest eucalyptus and coffee production, southeastern Brazil is the region with the highest

waste generation, producing almost half of the total amount of waste produced in the country (Fig. 1).

As such, with the data of the generated waste and the calorific values of each residue, it was possible to evaluate the amount of energy potentially available in each region of Brazil (Table 8).

The southeastern and southern regions of Brazil contain the greatest amount of energy available from crop residues studied. Brazil has great potential for bioenergy, totaling approximately 201 PJ of energy available (Fig. 2).

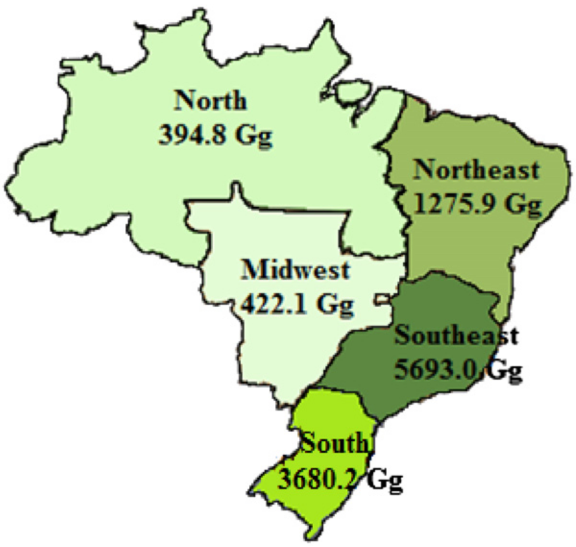

Fig. 1. Total amount of waste from timber (eucalyptus chip) and coffee (husk and wood) production in Brazil.

Table 8
Amount of energy available in the waste of eucalyptus and coffee production in Brazil.

Region	Wood (PJ)	Coffee husk (PJ)	Coffe wood (PJ)	Total (PJ)
North	4.3	0.6	2.0	7.0
Northeast	18.5	0.6	3.1	22.2
Southeast	50.2	9.4	41.3	100.9
South	60.5	0.5	2.8	63.8
Midwest	6.9	0.1	0.3	7.3
Brazil	140.4	11.3	49.5	201.3

Fig. 2. Map of the energy potential of waste from timber (eucalyptus chip) and coffee (husk and wood) production in Brazil.

Table 9
Energy availability of the waste.

Region	Electricity consumption EPE [37]	Energy availability of the waste	
	(GWh)	(GWh)	(%)
North	26237.0	1933.3	7.4
Northeast	71190.0	6179.8	8.7
Southeast	221976.0	28024.4	12.6
South	69563.0	17728.4	25.5
Midwest	26310.0	2034.7	7.7
Brazil	415227.0	55906.7	13.5

These residues can be used to generate thermal energy to dry agricultural products or to heat animal facilities, or as fuel to generate mechanical or electrical energy, using efficient thermochemical conversion technologies such as gasification.

According to Table 9, the wastes studied contained an amount of energy equivalent to 13.5% of the total electricity consumed in Brazil in 2010, not considering the efficiency of energy conversion process to be adopted.

The southern region of Brazil stands out for having the ability to serve 25.5% of its electricity demands from waste products.

Scarlat et al. [38] conducted a resource based assessment of biomass which is available each year for energy generation in Romania. The estimation of available biomass includes the residues generated from crop production, pruning of vineyards and orchards, forestry operations and wood processing. The amount of agricultural and forest residues available for bioenergy in Romania was estimated at 228.1 PJ on average, of which 137.1 PJ was from annual crop residues, 17.3 PJ residues from permanent crops and 73.7 PJ year^{-1} from forestry residues, firewood and wood processing by-products.

Perez et al. [39] studied the potential use of the waste from *Eucalyptus globulus* and *Eucalyptus nitens* as energy crops in Cantabria (North coast of Spain). The results showed calorific value of 17,384 and 17,927 kJ kg^{-1} in the adult stage for *E. globulus* and *E. nitens*, respectively, while in the young stage the values were 17,708 and 18,670 kJ kg^{-1} respectively. It could mean, just in the region of Cantabria, 205 TJ year^{-1}.

Hamzeh et al. [40] estimated the potentially available biomass resources in Iran and found that annual biomass potentials of Iran in terms of agricultural, animal and municipal wastes are 8.78×106, 7.7×106 and 3×106 t, respectively.

Wilson et al. [41] showed that over 12,604 million tones of agricultural waste are generated annually in Tanzania, with high potential from corn stalks and cobs (7.7 million tons), rice husk and straw (4.1 million tons), bagasse (447,030 t), wheat straw (232,000 t), sisal tow and flumes (46,000 t) and cashew nut shells (30,100 t).

Zhou et al. [42] evaluated the sustainable of agricultural and forest residue and municipal solid waste in China. The energy potentials of these resources in 2009, 2008, and 2007 are estimated to be 14.7, 3.9 and 0.2 EJ, respectively.

4. Conclusion

The biomasses studied showed chemical characteristics suitable for use as renewable solid fuel to generate energy through thermochemical conversion.

The wastes generated in the production of wood and coffee have great potential for energy production in Brazil and could be used as inputs for this sector. Southeastern Brazil is the main region of coffee and eucalyptus production of this country, producing about 50% of the total wastes from these activities.

The biomass energy conversion process is a technically and economically feasible alternative to generate energy for production systems, even in remote locations where access to the electrical distribution network is not yet available.

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References

[1] Magalhães EA, Silva JS, Silva JN, Oliveira Filho D. Donzeles SML. Casca de café associada à lenha como combustível para aquecimento indireto do ar de secagem. Revista Brasileira de Armazenamento—Especial Café 2008;10: 66–72.
[2] Melo FAO, Silva JN, Silva JS. Donzeles SML. Avaliação da utilização da palha de café para o aquecimento indireto de ar para a secagem de produtos agrícolas. Engenharia na Agricultura 2005;13:49–50.
[3] Saidur R, Abdelaziz EA, Demirbas A, Hossain MS, Mekhilef S. A review on biomass as a fuel for boilers. Renewable and Sustainable Energy Reviews 2011;15:2262–89.
[4] Annette E, Vladimir S, Evans TJ. Sustainability considerations for electricity generation from biomass. Renewable and Sustainable Energy Reviews 2010;14:1419–27.
[5] Kothari R, Buddhi D, Sawhney RL. Sources and technology for hydrogen production: a review. International Journal of Global Energy 2004;21: 154–78.
[6] Buragohain B, Mahanta P, Moholkar VS. Biomass gasification for decentralized power generation: The Indian perspective. Renewable and Sustainable Energy Reviews 2010;14(1):73–92.
[7] Bhattacharya SC, Salam PA, Pham HL, Ravindranath NH. Sustainable biomass production for energy in selected Asian countries. Biomass and Bioenergy 2003:471–82.
[8] Junmeng C., Ronghou L., Chunjian D. An assessment of biomass resources availability in Shanghai: 2005 analysis. Renewable and Sustainable Energy Reviews 2008; 12: 1997–2004.
[9] Saud T, Singh DP, Mandal TK, Gadi R, Pathak H, Saxena M, et al. Spatial distribution of biomass consumption as energy in rural areas of the Indo-Gangetic plain. Biomass and Bioenergy 2011;35:932–41.
[10] Mekhilef S, Saidur R, Safari A. Mustaffa WESB. Biomass energy in Malaysia: current state and prospects. Renewable and Sustainable Energy Reviews 2011;15:3360–70.
[11] Mirza UK, Ahmad N, Majeed T. An overview of biomass energy utilization in Pakistan. Renewable and Sustainable Energy Reviews 2008;12:1988–96.
[12] Kanianska R, Guštafíková T, Kizeková M, Kovanda J. Use of material flow accounting for assessment of energy savings: a case of biomass in Slovakia and the Czech Republic. Energy Policy 2011;39:2824–32.
[13] Steubing B, Zah R, Waeger P, Ludwig C. Bioenergy in Switzerland: assessing the domestic sustainable biomass potential. Renewable and Sustainable Energy Reviews 2010;14:2256–65.
[14] Clancy D, Breen JP, Thorne F, Wallace M. The influence of a renewable energy feed in tariff on the decision to produce biomass crops in Ireland. Energy Policy 2012;41:412–21.
[15] Boukis I, Vassilakos N, Kontopoulos G, Karellas S. Policy plan for the use of biomass and biofuels in Greece: Part I: available biomass and methodology. Renewable and Sustainable Energy Reviews 2009;13:971–85.
[16] Dinica V. Biomass power: exploring the diffusion challenges in Spain. Renewable and Sustainable Energy Reviews 2009;13:1551–9.
[17] García R, Pizarro C, Lavín AG, Bueno JL. Characterization of Spanish biomass wastes for energy use. Bioresource Technology 2012;103:249–58.
[18] Velázquez-Martí B, González EF, Cortés IL. Hernández DMS. Quantification of the residual biomass obtained from pruning of trees in Mediterranean olive groves. Biomass and Bioenergy 2011;35:3208–17.
[19] Panwar NL, Kothari R, Tyagi VV. Thermo chemical conversion of biomass—eco friendly energy routes. Renewable and Sustainable Energy Reviews 2012;16:1801–16.
[20] Bacellar AA. Rocha BRP. Wood-fuel biomass from the Madeira River: a sustainable option for electricity production in the Amazon region. Energy Policy 2010;38:5004–12.
[21] Simone M, Barontini F, Nicolella C, Tognotti L. Gasification of pelletized biomass in a pilot scale downdraft gasifier. Bioresource Technology 2012;116:403–12.
[22] ABNT, Associação Brasileira de Normas Técnicas. NBR 8112/83—Carvão Vegetal, Análise Imediata. Rio de janeiro; 1981. p. 6.
[23] Parikh L, Channiwala SA, Ghosal GK. A correlation for calculating elemental composition from proximate analysis of biomass materials. Fuel 2007;86: 1710–9.
[24] Parikh L, Channiwala SA, Ghosal GK. A correlation for calculating HHV from proximate analysis of solid fuels. Fuel 2005;84:487–94.
[25] IBGE—Instituto Brasileiro de Geografia e Estatística. Available from: www.ibge.gov.br; [accessed 12.01.12].
[26] Brammer IG, Bridgwater AV. The influence of feedstock drying on the performance and economics of a biomass gasifier-engine CHP System. Biomass and Bioenergy 2002;22:271–81.
[27] Pereira EG, Da Silva JN, Oliveira JL, Machado CS. Sustainable energy: a review of gasification technologies. Renewable and Sustainable Energy Reviews 2012;16:4753–62.
[28] Reed TB, Das A. Handbook of downdraft gasifier engine systems. Golden, Colo: Solar Technical Information Program, Solar Energy Research Institute; 1988 p. 140.
[29] Virmond E, De Sena RF, Albrecht W, Althoff CA, RFPM Moreira, José HJ. Characterisation of agroindustrial solid residues as biofuels and potential application in thermochemical processes. Waste Management 2012.
[30] Senneca O. Kinetics of pyrolysis, combustion and gasification of three biomass fuels. Fuel Processing Technology 2007;88:87–97.
[31] El may Y, Jeguirim M, Dorge S, Trouvé G, Said R. Study on the thermal behavior of different date palm residues: Characterization and devolatilization kinetics under inert and oxidative atmospheres. Energy 2012;44:702–9.
[32] Verma VK, Brama S, Delattin F, Laha P, Vandendael I, Hubin A, et al. Agropellets for domestic heating boilers: standard laboratory and real life performance. Applied Energy 2012;90:17–23.
[33] Wu MR, Schott DL, Lodewijks G. Physical properties of solid biomass. Biomass and Bioenergy 2011;35:2093–105.
[34] Higman C. Burgt MVD. Gasification. 2nd ed.Gulf Professional Publishing; 2008 p. 456.
[35] Spinelli R, Nati C, Pari L, Mescalchin E, Magagnotti N. Production and quality of biomass fuels from mechanized collection and processing of vineyard pruning residues. Applied Energy 2012;89:374–9.
[36] Sait HH, Hussain A, Salema AA, Ani FN. Pyrolysis and combustion kinetics of date palm biomass using thermogravimetric analysis. Bioresource Technology 2012;118:382–9.
[37] EPE, Empresa de Pesquisas Energéticas. Anuário estatístico de energia elétrica. Available from: http://www.epe.gov.br/AnuarioEstatisticodeEnergiaEletrica/Forms/Anurio.aspx; 2011 [accessed 15.07.12].
[38] Scarlat N, Blujdea V, Dallemand JF. Assessment of the availability of agricultural and forest residues for bioenergy production in Romania. Biomass and Bioenergy 2011;35:1995–2005.
[39] Perez S, Renedo CJ. Energy evaluation of the Eucalyptus globulus and the Eucalyptus nitens in the north of Spain (Cantabria). Thermochimica Acta 2006;451:57–64.
[40] Hamzeh Y, Ashori A, Mirzaei B, Abdulkhani A, Molaei M. Current and potential capabilities of biomass for green energy in Iran. Renewable and Sustainable Energy Reviews 2011;15:4934–8.
[41] Wilson L, Yang W, Blasiak W, John GR, Cuthbert F, Mhilu CF. Thermal characterization of tropical biomass feedstocks. Energy Conversion and Management 2011;52:191–8.
[42] Zhou X, Wang F, Hu H, Yang L, Guo P, Xiao B. Assessment of sustainable biomass resource for energy use in China. Biomass and Biomass 2011;35: 1–11.